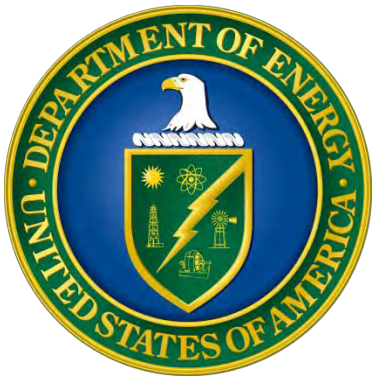
Advanced Vehicle Power Technology Alliance
Technical Workshop and Operations Report

Department of the Army
Department of Energy



October 5, 2011

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14. ABSTRACT
The Advanced Vehicle Power Technology Alliance (AVPTA) between the Department of Energy (DOE) and the Department of the Army (DA) underscores the urgency for energy security; in particular, an emphasis on developing advanced technologies that enable military ground vehicles to become significantly more energy efficient. Individually and collaboratively, the DOE and DA have a long history of successfully developing innovative vehicle technologies. This new alliance will accelerate the generation of inventive and creative energy-saving concepts that our Nation needs to achieve energy security.

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The Advanced Vehicle Power Technology Alliance (AVPTA) between the Department of Energy (DOE) and the Department of the Army (DA) underscores the urgency for energy security; in particular, an emphasis on developing advanced technologies that enable military ground vehicles to become significantly more energy efficient. Individually and collaboratively, the DOE and DA have a long history of successfully developing innovative vehicle technologies. This new alliance will accelerate the generation of inventive and creative energy-saving concepts that our Nation needs to achieve energy security.

"President Obama has made it clear that now is the time to secure our energy future," said Under Secretary of the Army the Honorable Joseph W. Westphal. "We must increase efficiency in Army vehicles to accomplish this vital national goal."

This report summarizes the technical output of the six working groups that convened at the Advanced Vehicle Power Technology (AVPT) Workshop in July 2011, where the Alliance Charter was first announced. DOE and DA experts are jointly developing a comprehensive Coordination Plan for the technical focus areas studied during the workshop.

The DOE-DA collaboration will ultimately support our military forces at home and abroad by developing vehicles that are lighter, more energy-efficient, less dependent on carbon fuels, and will maintain or improve their survivability and sustainability.

"They will provide the platforms for the next generation of fighting systems that are good for the environment and still meet the Army's military mission," Westphal added.

We sincerely thank Secretary of Energy the Honorable Steven Chu, the Honorable Joseph Westphal and the other dignitaries who addressed the workshop. Their presence emphasized to all the participants the important contribution they are making toward assisting the Nation in achieving its energy security goals. We also extend our personal thanks to the work group leaders and subject matter experts for their time, their willingness to share their expertise and whose collective contributions have made this a successful event.

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EXECUTIVE SUMMARY

The Advanced Vehicle Power Technology Alliance (AVPTA) Charter announcement and technical workshop convened in Detroit, MI on July 18-19, 2011. During the workshop plenary session, Dr. Steven Chu (Secretary of Energy) and Dr. Joseph W. Westphal (Under Secretary of the Army) announced the AVPTA Charter between the Department of Energy (DOE) and the Department of the Army (DA). The AVPTA is chartered "for the establishment of a joint technology research initiative in the area of ground vehicle power and energy technology research, development and transition." The AVPTA Mission is to leverage "resources to improve transition of technologies into both the commercial and military marketplace," and "industrial research and development (IRAD) involving commercial automotive and defense ground vehicle manufacturers to transition technologies and increase precompetitive research and development." The workshop was the first concrete manifestation of both departments' commitment to the Alliance.

The Workshop was attended by over 120 dignitaries, nationally recognized energy technology Subject Matter Experts (SMEs) and media representatives. Dignitaries addressing the event included the Honorable Carl Levin, United States Senator, Michigan; the Honorable Sharon E. Burke, Assistant Secretary of Defense for Operational Energy Plans and Programs; the Honorable Katherine Hammack, Assistant Secretary of the Army for Installations, Energy and the Environment; MG James Hodge, the Commanding General, Combined Arms Support Command and the Sustainment Center of Excellence; and Dr. Alan Taub, General Motors Vice President Global Research and Development.

The workshop centered on technical work groups, where 74 SMEs discussed issues and opportunities for collaboration in seven disciplines: Advanced Combustion Engines and Transmissions; Lightweight Structures and Materials; Energy Recovery and Thermal Management; Alternative Fuels and Lubricants; Hybrid Propulsion Systems; Batteries and Energy Storage; and Analytical Tools (Modeling and Simulation). Each discipline's work group was to identify, compile and document the following: DA and DOE high level strategic goals; strategic drivers derived from the strategic goals; research and development (R&D) topics linked to the strategic drivers; key technologies associated with R&D topics; current and objective metrics; and proposed prototype applications and timeframe. More than 30 R&D topics and 70 key technologies were identified. Materials, Thermal Management and Analytical Tools cross-cut all seven disciplines.

Using the workshop results, DA and DOE SMEs developed a list of action items by discipline, which fell into three categories: develop new or enhanced coordination opportunities; establish and/or improve project integration; and identify new possibilities for joint endeavors.

Existing partnerships between the agencies will brought under oversight of the Alliance. Also, several new joint endeavors were identified and collaborative planning for project concepts is already underway. These include activities in the areas of Energy Recovery and Thermal Management, Batteries and Energy Storage, and Lightweight Structures and Materials. A tangible outcome of this collaborative approach is that both departments may be better able to mitigate resource implications, in terms of time, money or personnel, and reduce risk by leveraging efforts that the other partner has already initiated.

The workshop co-hosts, Mr. Patrick Davis (Program Manager – Vehicle Technologies DOE-EERE) and Dr. Grace M. Bochenek (Director, US Army Tank Automotive Research, Development and Engineering Center) concluded the workshop attained its primary goal of reinvigorating the relationship between DA and DOE by facilitating point-to-point contact among Leadership and respective SMEs, that actions are achievable in the near-term to demonstrate the utility of this joint effort, and that AVPTA provides a crucial venue to continue collaboration between DOE and DA.

INTRODUCTION

There are two high level drivers that led to the development of the Advanced Vehicle Power Technology Alliance (AVPTA) between the Department of the Army (DA) and the Department of Energy (DOE). The first is the elevation of energy efficiency and security as points of emphasis throughout the Army and the Department of Defense (DOD) as a whole. For the Army, a major milestone in this was the development of the Army Energy Security Implementation Plan (AESIP) in 2009. Within the AESIP goal to Increase Energy Efficiency Across Platforms and Facilities, there was an objective to increase the efficiency of tactical equipment. At the DOD level, the Operational Energy Strategy is a principle-guidance document for the Department's approach to ensure energy security for operational forces.

The second was a call by the DOD for strengthened interagency partnering. This was set forth in its 2010 Quadrennial Defense Review. Energy security was identified as an excellent opportunity area for such a partnership. To this end, the DOE and DOD worked to craft a Memorandum of Understanding (MOU) to establish a partnering framework to enhance national energy security. This MOU is included as Appendix A. The MOU calls for the Departments to work together in a wide range of technical areas; including efficient transportation and overall energy efficiency.

DA and DOE worked together under the auspices of this MOU to develop a charter for working together in a wide range of vehicle technologies. This charter describing the alliance was signed by the Honorable Daniel B. Poneman, Deputy Secretary of Energy and the Honorable Joseph W. Westphal, Under Secretary of the Army and is included as Appendix B.

The DOE mission is to develop technologies that will reduce petroleum consumption and greenhouse gas emissions. A critical step in any new technology development is having it accepted and deployed in the marketplace. Teaming with DOD provides an attractive pathway for early utilization of the novel energy-saving ideas coming from the DOE research portfolio. These agencies strategic goals are summarized in Table 1 below.

Table 1: DOD & DOE Strategic Goals

DOD Operational Energy Strategy	DOE Vehicle Technology Program
Reduce Energy Demand: – Reduce: • Overall Operational Energy Demand • Mission Risks & Costs – Improve Energy Usage Efficiency	Reduce Petroleum Consumption
Expand & Secure Energy Supply: – Diversify Energy Sources – Protect Energy Supply Access	Reduce Green House Gas (GHG) Emissions[1]
Integrate Operational Energy Considerations Into: – Planning Activities and Force Development	

[1] Corresponds to DOD Strategic Driver

With strong support from senior leadership, the agencies worked together at the executive level to identify technical areas of mutual interest. It was determined that the technical areas should be further developed through a joint workshop that would include participants from industry and academia. This report summarizes that workshop and the near term path forward.

WORKSHOP OVERVIEW

The objective for the AVPTA Technical Workshop was to create a joint strategy for the development of ground vehicle energy technologies for the Department of the Army (DA) and the Department of Energy (DOE). The workshop laid the foundation for inter-agency collaboration in the near- and long-term.

The workshop brought together technical Subject Matter Experts (SMEs) from government, industry and academia to: identify commercial and military requirements; identify near- and long-term key technology development opportunities; quantify current and objective technical metrics; and identify high priority areas of collaboration with potential near-term impact.

SMEs from seven principal technical disciplines were invited to participate in focused Work Groups. Seventy-four (74) SMEs attended the Workshop and were joined by technical representatives from DA and DOE, some of whom rotated among the Work Groups to help identify areas of overlapping interest, while others worked within individual groups to provide DA and DOE context for the discussions. The principle focus topics by Work Group were:

Work Group 1 - Advanced Combustion Engines & Transmissions

> Advanced air-fuel management systems and novel combustion regimes have the potential to dramatically increase efficiency and power density, while at the same time reducing emissions. Meeting the challenge of developing and optimizing the combustion of common petroleum fuels, including Jet Propellant-8 (JP8), or biofuels in advanced engines requires a new level of the understanding of the physical and chemical phenomena of the Direct Injection (DI) diesel engine, which will be strongly affected by the different fuel properties which in turn affect fuel/air mixture preparation, combustion and emissions.
>
> Advanced transmissions can allow the engine to operate more frequently in regions of high efficiency and transmit more torque while maintaining drivability. Of particular interest for further Research & Development (R&D) are approaches and devices to increase launch-assist device efficiency, and to increase the number of gear ratios. Among possible options for investigation are higher gear count automatic transmissions, Dual Clutch Transmissions (DCT), wet and dry clutch launch devices, multi damper torque converters, Continuously Variable Transmissions (CVTs), and binary transmissions.

Work Group 2 - Lightweight Structures & Materials

> Reduction of vehicle gross weight is an effective approach to reduce energy consumption during the vehicle usage, regardless of their energy sources (e.g., liquid fuels or electric batteries). Lightweight materials such as aluminum (Al) alloys, magnesium (Mg) alloys, high strength steel, and carbon-polymer composites have been considered to replace low carbon steels conventionally used in automotive components. Challenges exist, however, to integrate components made of these

lightweight materials into vehicle structures to achieve maximum weight reduction, while maintaining structural rigidity, crash safety, production quality and cost parity.

Work Group 3 - Energy Recovery & Thermal Management

In current vehicles, approximately 60% of the chemical energy of fuel is lost in the form of waste heat, dissipated by the exhaust and cooling systems. The former offers high-grade heat that approaches temperatures of 800^{o}C while the latter is a considerably more modest heat source at approximately 120^{o}C. Of significant interest are exhaust heat recovery systems, including Organic Rankine cycles, as well as mechanical and electrical turbo-compounding. In addition, through the development of cost-competitive advanced second generation thermoelectric (TE) devices for vehicle applications vehicle fuel efficiency, performance, and emissions can be improved. Thermo-electric devices can convert engine waste heat to useful electrical power, to be used either assisting propulsion or for powering hotel loads. By integrating high Figure of Merit TE devices in the vehicle architecture, thermal management of vehicles can become significantly more efficient.

Work Group 4 - Alternative Fuels & Lubricants

Alternative fuels and lubricants can facilitate or enhance conventional engine technology, as well as advanced combustion regime engine operation such as Homogeneous Charge Compression Ignition (HCCI) or Low Temperature Combustion. For alternative fuels, the focus should be on drop-in fuels or blend stocks that displace petroleum-derived fuels in vehicle applications without significant infrastructure changes or requirements. New developments in base oil and additive packages can reduce viscosity while maintaining temperature requirements, thereby improving engine and transmission efficiency.

Work Group 5a/5b - Hybrid Propulsion Systems including Batteries/Energy Storage

Electric drive options range from mild battery-alternator systems to full parallel and series systems or all electric drive, and require engineering trade-offs between fuel consumption benefit and system complexity, reliability and cost. However, to achieve efficient solutions, electrical materials and devices will require higher conversion efficiencies and power/energy densities than are currently possible. The next generation electric drive vehicles will benefit from improved and lower cost batteries, novel electric motors, thermoelectric waste heat recovery, and power electronic devices and electrical topologies that are capable of handling increased loads and multiple combinations of sources and accessories.

Note: Due to the size of the group, and the breadth of the technology area, the group immediately decided to split into two Sub-Work Groups. Work Group 5a primarily focused on hybrid system power electronics and electric machines while Work Group 5b focused on hybrid system electricity storage in the forms of batteries and

capacitors. The Work Groups convened separately, but their respective focus areas are inexorably linked within the overall contexts of Battery-Electric, Hybrid-Electric and/or Plug-in Hybrid-Electric Vehicle (BEV, HEV and/or PHEV) propulsion systems.

Work Group 6 - Analytical Tools (Simulation & Modeling)

Diverse fuel sources, advanced combustion modes, hybrid/electrified powertrains, energy harvest/waste heat recovery technologies, and using lightweight materials substantially elevate the complexities of efficient vehicle powertrain systems and impose critical challenges for system integration and control. These efficient vehicle powertrain sub-systems, with new characteristics and strongly interactive dynamics, necessitate research on system integration and advanced control strategies. An integrated and analytical systems approach ensure that the various sub-systems of the vehicle work seamlessly, reliably and synergistically to optimize coordination so as to maximize vehicle energy efficiency, power density and emission reduction potential in real-world applications. Through state-of-the-art modeling and analysis, concepts and strategies can be screened during the vehicle design stage, and most promising candidates and key pathways to bring them to realization in an effective time frame can be identified. Critical components and/or systems needing specific development can also be identified and analyzed with simulation tools.

Appendix C (Breakout Session Subject Matter Experts) contains a complete list of the SME names, their respective organization, and the Work Group in which they participated.

A “Moderator” and “Recorder” was designated for each Work Group: they are identified within the Appendix C. The Moderator led the Work Group to maintain technical focus and presented the Work Group’s work product to a Summary Session attended by all of the Workshop participants. The Recorder facilitated Work Group logistics and data/information documentation.

TECHNICAL SUMMARY

The synthesized and compiled work product and path forward of the seven Work Groups is summarized herein. The work product is presented in top/down order starting with respective Departments of Defense and Energy publicly documented Strategic Goals. Each successive 'layer' of information and data is derived from and expands upon the preceding layer in the following sequence:

- Departments of Defense & Energy publicly documented Strategic Goals
- Departments of Defense & Energy publicly documented Strategic Drivers
- Work Groups identified:
  - Research & Development (R&D) Topics
  - Key Technology Subsets of the R&D Topics
  - Current & Objective Metrics
  - Proposed Prototype Applications & Timeframe
- Post-Workshop data/information analysis
  - Cross-cutting Technologies assessment

The collected data is reflected in Appendix E. In every case, the Work Groups identified common metrics for their technical areas as reported in Table E-4. These metrics will have to be carefully reassessed in the course of planning any potential joint endeavors to ensure they are current. Additionally, the Work Groups projected when operational prototypes would be available for integration into military or commercial vehicle applications. Table 6 reports these findings to include the potential platforms for demonstration and timing. There are many near to mid-term (out to 2016) opportunities for joint technology demonstrations.

Following the workshop, the collected data was analyzed in order to identify priority R&D topics. This post-workshop analysis is reported in Appendix F. The data was analyzed to identify:

- R&D Topics Cross-referenced by Key Technology (Table F-2)
- Work Group Defined Technical Strategic Drivers (Table F-3)
- Work Group Defined Potential Strategic Drivers/Requirements Trade-off Opportunities (Table F-4)

It should be noted that the information and data contained within the following tables is the result of a rigorous review, analysis, synthesis and compilation processing of material documented in electronic and hard copy formats. After the workshop the information and materials developed were consolidated and categorized into the Data/Information Tables in Appendix F. Of particular note are the areas where cross-cuts were identified that expand the scope of specific working

groups were documented. A specific example of the last point is materials that cross-cuts all seven Work Groups, but affects the Lightweight Structures & Materials Work Group in different contexts than within the technical discipline description contained within the Workshop Overview. Materials issues cited include: operation under high ambient/operating heat conditions; parasitic friction reduction; and within power electronic devices/electric machines.

Approximately two weeks after the Workshop adjourned, a series of follow-up questions were posed to the respective Work Group Leaders. The questions ranged from technical, regarding observations and findings of the work group; to personal, about how the Workshop was conducted and recommendations for future event improvements. These responses help to provide additional context for the data collected during the Workshop by capturing the thoughts of the Work Group Leaders after they had an opportunity to reflect on the proceedings. The responses were specific to the work groups and did not reveal any cross-cutting themes. Selected responses on technical questions are documented in Appendix G.

COORDINATION PLANS

Approximately a month after the Workshop concluded, Mr. Davis and Dr. Bochenek met to discuss their perspectives on the workshop and provide direction for a near-term course of action. The decision was made that the next step would be to have a technical lead representative from each agency collaborate on the development of a Coordination Plan for their respective technology focus area.

The Coordination Plans have three tiers, with each tier reflecting an increasing commitment of resources. Coordination Opportunities were defined as means to ensure regular exchange of information between technical counterparts at each agency. There are many ongoing examples of such coordination, so this primarily focused on recommitting to existing venues but the need for several new start coordination bodies were identified. The Project Integration area was defines as means to maintain joint visibility of projects of common interest, without dedicating new financial resources. Joint planning and budgeting activities also fit this category. The final area, Potential Joint Endeavors, will entail the dedication of new financial resources by either or both of the agencies.

Several Coordination Opportunities and means for Project Integration which cross-cut multiple technology areas were identified. These are highlighted below:

- Coordination Opportunities
  - Inter-Agency Power Group (IAPG) meetings
  - DOE Vehicle Technologies Program Annual Merit Review
  - Annual Army and DOE conducted technical meetings
  - Directions in Engine-Efficiency and Emissions Research (DEER) Conference
  - Ground Vehicle Systems Engineering & Technology Symposium
  - Attend the project kickoffs of mutual interest
- Project Integration
  - Annual Advanced Vehicle Power Technology Alliance Review & Planning Meeting
    - Establish this meeting as a collaboration forum for all focus groups
    - Present opportunities to share information between DOE and DA, review collaborative projects in progress, and propose new ones
    - Joint review of proposals

The Coordination Plans for each of the Work Groups follow.

Work Group 1 - Advanced Combustion Engines & Transmissions Coordination Plan

A common goal of the DOE and DA is to reduce the fuel consumption and emissions of advanced internal combustion engines for both civilian and military applications. Although industry is focused on reducing fuel consumption in general, DOE is focused more specifically on the reduction of petroleum consumption. Other industry concerns are low-cost manufacturing, durable and reliable systems, and profitability. Concerns for the Army include use of a wide-ignition range quality fuel (JP-8 and DF-2 on a global basis), power density (packaging constraints), and low heat rejection to achieve high mobility for tactical and combat operations.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- SuperTruck project reviews
  - DOE is pursuing a wide range of vehicle efficiency measures; DA to monitor and assess for applicability to military platforms
- Advanced Engine Combustion MOU
  - This DOE MOU establishes a means for industry to influence engine research at the National Laboratories, DA has used this forum to monitor basic research
- Advanced Combustion and Emission Control (ACEC) Technical Team Meetings
  - DA has participated in this Technical Team since its inception in 1993 and it provides a means to monitor applied research and development
- Advanced Engine Cross-Cut Team Meetings
- 21st Century Truck Partnership Meetings

Project Integration

- DA to continue participating in ACEC United States Driving Research & Innovation for Vehicle efficiency and Energy sustainability (US DRIVE) team meetings and reviews
  - Opportunity to participate in strategic planning of engine research activities
- DA to continue participating in Combustion MOU biennial reviews
  - Access to basic combustion research conducted under the MOU
- DA to continue monitoring DOE engine research activities relevant to military ground vehicles performed by Sandia, Oak Ridge, and Argonne National Laboratories
  - Projects outside the scope of the MOU
- DOE to participate in DA-sponsored Automotive Research Center (ARC) powertrain activities
- DOE to participate in DA-sponsored Low Temperature Research Center (LTRC) engine research

Potential Joint Endeavors

The technical areas listed below have been identified between DA and DOE as potential areas for coordinated/joint activities (such as joint solicitations, co-funded projects, or other options for closer working relations).

- Ignition Models for Heavy Hydrocarbon Fuels (1 to 2 years): Predictive tools and models (including physically based Computational Fluid Dynamic (CFD) models and accurate

reduced kinetic models) and validation of these models and development of vehicle system level models. Predictive computational design and simulation tools will shrink engine development times, reduce development costs, enable evaluation of breakthroughs in engine technologies and alternative fuels use, and accelerate time to market or help to accomplish the military mission.

- Sensors for Combustion Control in Advanced Direct Injection Engines (1 to 2 years): In-cylinder combustion control and sensors, including in-cylinder pressure sensors, low cost/durable sensors, and model-based controls. This will improve engine efficiency and minimize emissions for any fuel type.
- Variable Area Fuel Injection Technology (1 to 2 years): High pressure fuel injection, multi-pulse fuel injection, micro injectors, spray mixture fundamentals, nozzle designs, and materials for improved engine combustion.
- Advanced Boosting Systems (1 to 2 years): Novel designs and high temperature materials to enable high power densities for improved mobility.
- Thermal Management : Better manage engine heat rejection through fan control technology, low heat rejection designs, combustion strategies, such as Low Temperature Combustion (LTC), and more efficient vehicle heating and cooling

Work Group 2 - Lightweight Structures & Materials Coordination Plan

Reducing vehicle weight is critical to both DA and DOE to increase vehicle capability and/or reduce fuel consumption. The goal is to cost effectively reduce the weight of the vehicle while maintaining safety, performance (including Army requirements on survivability), and recyclability. DOE actively supports this area and DA developed significant lightweighting expertise through the Future Combat System (FCS) program.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- Lightweight Materials Working Group (LMWG)
  - DA to establish a Work Group that will regularly coordinate and establish initiatives in the areas of lightweight materials (e.g., composites, aluminum, magnesium, steel and titanium), multi-material structural design, joining, and manufacturing processes.
- Project Review Meetings
  - Holistic design methods for lightweight multi-material vehicles was deemed the most important topic at the workshop. This complex topic addresses all aspects of lightweighting, including requirements definition, software tools / model development, and manufacturing processes (assembly and part forming).

Project Integration

- DA and DOE will assign representatives to participate in project review meetings. This will allow both organizations to assess and develop opportunities for future joint endeavors, as well as build both organizations' expertise in this rapidly changing technology area.
  - DOE projects in lightweight materials: the Magnesium Intensive Front End, the Multi-Material Vehicle, and the industry lead project in Low Cost Manufacturing of Carbon Fiber Components.
  - DOE Phase III Small-Business Innovative Research (SBIR) Project: Carbon fiber composite manufacturing for automotive.
  - Low Cost Carbon Fiber Production: Oak ridge National Laboratory (ONRL) has developed a low cost carbon fiber production method. The DA could participate in ongoing research and/or utilize the low cost carbon fiber for a military application.

Potential Joint Endeavors

- DA Lightweight Vehicle Structure Project: This project is already underway; it was initiated under a prior agreement. This multi-material design and manufacturing project will redesign for weight optimization and manufacture, and test a military vehicle to demonstrate the current level of affordable weight reduction.
- Multi-material Joining (welding, mechanical and adhesive joining) (FY13 – FY18): The major elements to be developed are:
  - Multi-material joint design
  - Multi-material joining process design
  - Material characterization
  - Modeling and simulation of materials and processes
  - Physical testing and simulation model validation
  - Standards development

Work Group 3 - Energy Recovery & Thermal Management Coordination Plan

Thermal Management (TM) is a critical player in achieving energy efficiency. No matter how efficient vehicles become, they will always generate heat. TM must find a way to not only operate components in harsh environments, but to also recover as much waste heat as possible to increase overall vehicle efficiency. Optimizing the manner in which we transport and dispose of heat is critical. In particular, DA has cabins that have few access points to the outside and heat builds inside. The engine compartment also requires adequate cooling. Joint focus areas will center on these two critical areas: 1) efficiently dealing with heat generated and 2) recovering waste heat into usable energy.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- DA to invite DOE into the Research, Development & Engineering Command (RDECOM) Solid State Conversion Devices roadmapping workgroup.

Project Integration

- DA to work with DOE to identify a military enhancement to the efforts awarded under DE-FOA-0000239 – Area of Interest 6—Thermoelectrics and Enabling Engine Technologies.
  - The goal will be to identify opportunities for the Army to leverage this investment to apply the core technologies to tactical vehicles with accelerated timing and at reduced investment levels.
- DA will monitor the following DOE-sponsored activities to evaluate for future development and to build DA's expertise in this emerging technology area
  - Combined TE and Organic Rankine Cycle at Pacific Northwest National Laboratory (PNNL) and Communications-Electronics Research, Development & Engineering Center (CERDEC)
  - Energy Balance Modeling & Simulation at DOE EERE
  - Combined Cooling Loops at National Renewable Energy Laboratory (NREL)
  - Advanced Air-cooled Heat Exchangers at Sandia National Laboratory
- The DOE will monitor DA's activity in developing unique vehicular applications of thermal electric materials.

Potential Joint Endeavors

- DA will identify the incremental Army funding required to meet the objectives identified of DE-FOA-0000239 – Area of Interest 6—Thermoelectrics and Enabling Engine Technologies (FY11-14).
  - The goal will be to assess of the program's phase II deliverables in a military platform and validate the projections of an up to 5% improvement in overall vehicle fuel efficiency
- DA and DOE will work together to develop a joint test standards for the thermoelectric performance assessment. The Army Research Laboratory (ARL) and DOE will focus at the material level, TARDEC will focus at the subsystem level and there will be collaboration at the module level.
  - This activity will result in the common assessment of performance which will be useful in steering future research and application directions.

Work Group 4 - Alternative Fuels & Lubricants Coordination Plan

Alternative fuels and lubricants contribute to reducing the reliance on petroleum from both the supply and demand side. These are prime areas of interest to both the DOD and DOE. DA has a key responsibility to conduct the Research, Development, Testing & Engineering (RDT&E) for fuels and lubricants as the DOD Executive Agent for ground fuels and lubricants. The Fuels and Lubricants Technology Subprogram of the DOE-EERE Vehicle Technologies Program is the lead research and development entity within the DOE addressing this topic for the commercial sector. The focus of this collaboration is on research and testing of alternative fuels and lubricants that support reduced petroleum consumption in medium and heavy duty vehicle applications.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- Lubrication in Internal Combustion Engines Consortium conducted by the Sloan Automotive Laboratory at Massachusetts Institute of Technology
  - DA's participation has been recommended by DOE to leverage technology being developed by this automotive manufacturer centric consortium
- Society of Automotive Engineers
  - Coordinate participation at relevant committee meetings that support new Corporate Average Fuel Economy (CAFE) standards for Heavy Duty (HD) vehicles
  - Invite DOE participation in the DA-chaired Axle Efficiency Task Force

Project Integration

- Joint development of fit-for-purpose criteria and test methods for alternative diesel fuels.
  - DOE to review DA development of apparatus to measure bulk modulus of a fuel currently underway at the TARDEC Fuels and Lubricants Research Facility (TFLRF). Identify path forward to develop and validate this apparatus as part of a new Federal Test Method.
- Joint development of fuel economy test methods for engine oils and gear lubricants.
  - DOE will monitor and review DA's development of an engine oil fuel efficiency method utilizing a legacy military engine scheduled for completion in FY12.
  - Identify a modern diesel engine of interest to both the military and commercial sector for joint projects to develop fuel economy test methods for engine oils.
  - Identify medium and heavy duty axle(s) of interest to both the military and commercial sector for joint projects to develop fuel efficiency test methods for gear lubricants.

Potential Joint Endeavors

- Fuel Efficient Engine Oils
  - Develop bench-top/component rig test method(s) that correlate to fuel economy test for use in screening low friction components, surface treatments and new engine oils. (FY12-FY14)
  - Develop engine oil with improved fuel economy benefit. (FY12-FY16)
  - Test low friction components and surface treatments in older technology engines to improve fuel efficiency of legacy fleet. (FY14-15)
  - Investigate innovative lubrication strategies (e.g., split level). (FY14-15)
- Fuel Efficient Gear Lubricants
  - Conduct business case analysis to quantify expected fuel efficiency benefits for medium and heavy duty vehicles attributable to improved axle lubricants. (FY13)
  - Develop dynamometer test method for medium and heavy duty vehicles to quantify fuel efficiency benefit attributable to improved axle lubricants. (FY13-FY14)
  - Develop benchtop/component rig test method that correlates to dynamometer test for use in screening new gear lubricants for fuel efficiency benefit. (FY14-FY15).
  - Develop gear lubricant with improved fuel efficiency benefit. (FY15-FY17)
- Drop-in Alternative Diesel Fuels
  - Develop criteria that establish the suitability of any diesel fuel for use in the systems that store, handle, distribute or consume it. (FY12-FY14)
  - Develop test methods to better characterize non-petroleum diesel fuel quality and support integration of alternative diesel fuels into fuel supply. (FY12-FY16)

Work Group 5a - Hybrid Propulsion Systems Coordination Plan

DOE and DA have different requirements and end goals in the area of hybrid propulsion systems. DOE's focus is on producing electric traction drives as a means of reducing petroleum consumption while the Army needs on-board power production for its vehicles for communications, weapons platforms, etc. However, the resulting technology needs do have some commonality, and both require high temperature capabilities to reduce cooling needs.

DOE has a well-defined set of targets for weight, volume, cost, and efficiency and the Army also needs smaller, lighter systems. DOE efforts are driven primarily by cost, while Army efforts are driven by mission requirements (e.g., high-temperature applications). The Army needs high-temperature power electronics, and DOE could make use of such systems, but only if cost targets are met.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- Participation in the Wide Band Gap (WBG) Power Electronics Summit
  - DA is an active participant in this working group. The next discussion session will be a detailed roadmapping effort hosted by ORNL in Fall 2011.
- Coordination Opportunities
  - National Laboratories
  - Office of Naval Research (ONR)
  - Air Force
  - R&D project updates (new DOE industry awards FY 11)

Project Integration

Because of different requirements and emphasis, sharing R&D results would be the most beneficial approach. For example, the DOE database of wide band-gap device performance and the performance characteristics of Army all-silicon carbide (SiC) inverter projects could be shared. Army personnel are invited to the DOE Kickoff and AMR meetings and to provide comments on the DOE projects.

- The Army is developing power converters based on silicon carbide (SiC) power semiconductor modules. These allow for a reduction in the thermal burden of On-Board Vehicle Power (OBVP) and hybrid electric propulsion systems in commercial and military vehicles due to higher inlet coolant temperatures and lower switching and conduction losses.
  - DOE will be invited to participate in the In-Process Reviews (IPRs) for DA programs W56HZV-10-C-0113 (SAIC), W56HZV-10-C-0114 (Teledyne), and W56HZV-10-C-0115 (RCT Systems).

Project Integration (Cont.)

- DA is finalizing a Cooperative Research and Development Agreement (CRADA) with General Motors Research Laboratory to share and exchange research and test results of both SiC and gallium nitride (GaN) power electronics.
  - DOE will be invited to participate in this collaborative effort.
- DA will monitor the DOE sponsored projects awarded under DE-FOA-0000472 – REACT.
  - These projects seek to develop electric machines with reduced rare-earth content for automotive and wind applications. DA will leverage this investment for military applications including OBVP and hybrid electric propulsion.

Potential Joint Endeavors

- Wide Band Gap Power Electronics (3 years). The automotive industry has also expressed a strong interest in SiC and has involvement in the development of GaN to allow higher temperature operation and employ higher switching frequencies for improved packaging of the power electronic conversion components in hybrid electric vehicles.
- Rare Earth Substitutes (2 years): Most electric machines used in hybrid electric vehicles use rare earth permanent magnets (neodymium iron boron and samarium cobalt) to maximize power and torque density. Nearly all rare earth magnets are imported from China; however China has recently begun limiting exports of rare-earth magnets.
  - DOE is developing new electric machines with reduced rare earth content for both automotive and wind applications. The Army will seek to partner with DOE on the development of an electric machine with reduced rare earth content tailored to military OBVP and hybrid electric systems. This machine would also be applicable to the heavy commercial vehicle market.

Work Group 5b - Batteries/Energy Storage Coordination Plan

The Battery Focus Areas of Interest includes energy storage technologies, specifically improving existing battery chemistries, developing advanced battery technologies (high power and high energy systems), and ultracapacitor research.

DA goals are to improve the availability of onboard power, reduce energy demand/ consumption, expand the energy supply to military operations and build energy security into future forces. DA-specific applications are a silent watch capability, electromagnetic armor and Starting/Lighting/Igniting (SLI), while DOE highlighted hybrid electric vehicles and electric vehicles. DOE goals are to reduce the petroleum demand, reduce greenhouse gas emissions and promote US economic competitiveness in advanced vehicle technologies.

Advanced lead-acid batteries, ultracapacitors, lithium-ion batteries, lithium sulfur and lithium-air batteries were identified as joint areas of interest between DA and DOE. Both agencies are also interested in improving on-board safety, developing battery test protocols and promoting codes and standards.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- The Lithium Battery Safety Group for intergovernmental testing coordination, SAE International (SAE) J2929 committee for safety requirements and testing, and National Highway Safety Administration for transportability standards
  - Coordinated participation in the development of standards and best practices will ensure commonality in these for dual-use products
- Coordination of advanced research activities with third parties to include Army Research Laboratory (ARL), Advanced Research Projects Agency – Energy (ARPA-E), US Advanced Battery Consortium, Argonne National Laboratory (ANL), DOD Power Sources Technology Work Group, Common Industrial Partners and University research partnerships.
  - This coordination will maximize efficiency of research investments and expedite the transition of advanced technologies into dual use platforms.
- DA and DOE will evaluate instrumentation, facilities and resources each agency has available for collaboration.

Project Integration

- DA and DOE will continue to coordinate the development of testing and safety standards.
  - This activity will result in the common assessment of performance which will reduce the energy storage systems development/validation costs and be useful in steering future research and application directions.
- DA and DOE will coordinate advanced research activities with commercial industrial contractors (such as Quallion, 3M, GM, Exide, Optodot, A123, Enerdel, SAFT, TIAX, TDA, and Inventek) and University research institutes. This coordination will include collaborative development of solicitations for future projects.
  - Coordination of projects will increase the efficiency of research investments and maximize the development of dual use technologies.

Potential Joint Endeavors

- DA is currently developing/evaluating Li-ion batteries in 6T group form factors. DA/DOE will develop the dual use capability of these batteries in support of anti-idling and start/stop applications for commercial truck and vehicle applications. (FY11-FY14)
- Computer-Aided Engineering for electric drive vehicle Batteries (CAEBAT) program (now funded by DOE) for modeling and simulation. (FY12-FY15)
- DA and DOE will work together on advanced battery material projects (including electrolyte, cathode, anode and separator work). This effort will leverage and build on activities being carried out at the National Laboratories (especially ANL) and ARL. (FY11- FY16)

Work Group 6 - Analytical Tools (Modeling & Simulation – M&S) Coordination Plan

The Analytical Tools Focus Area seeks to identify opportunities for collaboration between DA and DOE related to the development and utilization of state-of-the-art vehicle modeling, simulation and analysis tools. These tools are necessary to accomplish the systems integration and control strategy development required for advanced vehicle sub-systems to work seamlessly, reliably and synergistically to maximize vehicle energy efficiency while optimizing performance.

DA and DOE share the common goal of reducing petroleum consumption through the development of advanced ground vehicle energy technologies. As new and novel propulsion systems of increasing complexity are investigated, it is imperative that they be considered within the context of the overall vehicle system. The use of robust modeling and analysis tools will not only enable the integration and control strategies of these components and subsystems, but also guide and focus research on the most promising technologies of interest to DOE and DA.

Coordination Opportunities

DA and DOE have identified the following venues for coordination:

- Annual Automotive Research Center (ARC) Conference
  - Leverage the world-class academic research in the DA-sponsored ARC to assist with solving the DOE modeling and simulation problems
- DOD Power and Energy Community of Interest Modeling and Simulation Working Group
- Expand the current joint Army, Air Force and Navy effort for energy efficiency M&S to include the DOE
- Joint collaboration on the CAEBAT project
  - CAEBAT is an industry effort to define modeling of batteries for use in Computer Aided Engineering (CAE), to include batteries in system-level modeling and simulation. Both DOE and DA have representation in CAEBAT
- Joint collaboration to leverage results of ORNL's Large Scale Duty Cycle (LSDC) project
  - Duty cycles are a major gap in current M&S efforts on both sides. DA will use the DOE tools to help define military ground system duty cycles.
- Share the National Renewable Energy Laboratory Drive-cycle Rapid Investigation, Visualization & Evaluation (NREL DRIVE) tool with DA, and use it as basis of future collaboration
  - Another tool to capture ground vehicle duty cycles, but from an analytical approach
- Joint collaboration on modeling impact of friction on military vehicle fuel economy (joint effort with ANL, Ricardo, Mahle, and TARDEC)
  - The Fuel Efficient Demonstrator (FED) project
- Leverage current joint membership of SAE committee to produce standards
  - Significant gap is the lack of industry standards for M&S. Both DOE and DA have representation on the SAE committee

Project Integration

In addition to the near-term coordination opportunities identified by DA and DOE, other opportunities for potential project integration include:

- Develop a framework to allow model sharing and interoperability
  - Coordination of the standards and infrastructure will allow models to be shared, and increase utility for both partners
- Promote modeling and simulation to universities to prepare model-based systems engineers
  - The major resource for M&S is a skilled workforce.

Potential Joint Endeavors

- Analysis tools for capturing duty cycles and fully burdened lifecycle costs (FY12 – FY14).
  - As vehicles become electrified, and powertrain systems become more complex, the potential trade-space increases exponentially
  - The M&S requirements increase in two major ways
    - the need to characterize duty cycles capturing automotive propulsion, hybrids, and energy devices (production, storage and demand)
    - prediction of sustainment and logistics costs.
  - DA plans to develop tools to address these points and expand previous duty cycle experiments and coordinate with DOE on Class 8 trucks
  - A key aspect of DA's proposed duty cycle analysis method is that it would enable one to define duty cycles that lead to specific, measurable effects. This approach features inherent traceability of design parameters to performance requirements, which would provide crucial insight early in the vehicle development process that would not otherwise be available.
- Sub-system modeling topics – Batteries (FY12-FY15)
  - Batteries have become a very significant subsystem, with few acceptable tools for modeling in an automotive setting
    - Work Group 6 will coordinate with Work Group 5b (Batteries/Energy Storage) to develop a lower fidelity model for vehicle system integration
  - A specific challenge is capturing the effect of true duty-cycle demands on
    - state-of-charge
    - state-of-health
    - thermal management
  - TARDEC will take the lead in applying new M&S techniques to the evaluation of battery performance and safety in a military ground vehicle.
- Joint evaluation of model-based systems engineering tools/commercial software (FY12)
  - Joint efforts to evaluate model-based systems engineering tools and commercially available M&S solutions will benefit the alliance.
  - This work would provide significant contributions to formulating standard methods and increasing efficiency for a wide range of joint DOE-Army activities in modeling, simulation, testing, and validation.

ALLIANCE INITIAL OPERATING CONSTRUCT

The AVPTA Charter provides the basic structure under which the Alliance will conduct its operations, as organized by the TARDEC Director and Vehicle Technologies Program Manager. It will include quarterly leadership meetings and regular engagement between the organizations technical area leads.

The quarterly leadership meetings will be aligned to the overall planning, programming, budgeting and execution cycles. In the first quarter of the fiscal year the meeting will be focused on reviewing the current portfolio of each organization. This will be followed by a session to discuss gaps in the individual and joint portfolio in light of emerging strategic and operational drivers. The meeting in the third quarter will be focused on joint planning to support the respective agency's budgeting process. The final meeting of the fiscal year will be a joint technical meeting.

As the organizations begin to normalize this operating cycle, the first official quarterly meeting will be held in December 2011. This inaugural meeting will be focused on the joint review and approval of the program plans for the identified potential joint endeavors which are briefly highlighted within this report.

In order to ensure productive meetings at the leadership level, it is anticipated that the seven technical area leads will have to conduct additional exchanges outside of the leadership meeting cycle. The conduct of the technical area meetings will initially be driven by the need to develop joint project plans for review at the first leadership quarterly meeting. Due to the varying degrees of opportunity for collaboration across the Work Groups, the future conduct of the technical area exchange will be defined on a case by case basis.

CONCLUSIONS, RECOMMENDATIONS & NEXT STEPS

Conclusions

- The Workshop attained its primary goal of reinvigorating the relationship between DA and DOE by facilitating point-to-point contact among Leadership and respective SMEs.
- All of the Work Groups identified at least one Key Technology of mutual DOD/DA/DOE interest.
- Three of the Work Groups (Materials, Thermal Management and Analytical Tools [Modeling & Simulation)] technology focus areas cross-cut all seven Work Groups.
- On-going and near-term opportunities for joint activities were identified by several of the Work Groups; e.g., Batteries/Energy Storage, Materials and Analytical Modeling.

Recommendations

- Implement the DA/DOE technology focus-based 'Coordination Plans'
- Enhance and expand communications among and between DA/DOD and DOE with particular emphasis on meetings and events of common interest.
- AVPTA leadership determination if a Senior Advisory Board is desired.
- Develop a plan and process to integrate industry into near-term AVPTA activities.
- Develop a common, technology-based lexicon among DA/DOD/DOE to enhance communication clarity.
- Broaden the technical scope of the Materials, Thermal Management and Analytical Tools Work Groups to include cross-cut activities cited by the remaining Work Groups. An example is to expand Materials beyond light-weighting to include high-temperature operating conditions/resistance, friction reduction, etc.

Next Steps

- Identify and implement Coordination Plan high value opportunities that can be initiated in the near-term.
  - Initial review of the Coordination Plans indicates high value opportunities in thermoelectrics, light-weighting and batteries.
- Develop a calendar of regularly scheduled AVPTA activities review meetings to be co-chaired by Mr. Davis and Dr. Bochenek. Proposed meeting frequency is quarterly.
- Identify a preliminary target date, participants list and agenda for the inaugural AVPTA Annual Review Meeting specified within Section V. (Coordination) of the AVPTA Charter.
  - The objective of the yearly meeting is to "assess results, update requirements and determine new joint efforts" of the Alliance.

APPENDIX A
DOD/DOE MEMORANDUM OF UNDERSTANDING

Memorandum of Understanding

Between

U. S. Department of Energy

And

U. S. Department of Defense

Concerning Cooperation in a Strategic Partnership to Enhance Energy Security

I. Purpose

The purpose of this Memorandum of Understanding (MOU) is to identify a framework for cooperation and partnership between the Department of Energy (DOE) and the Department of Defense (DOD), hereafter referred to as the Parties, to strengthen coordination of efforts to enhance national energy security, and demonstrate Federal Government leadership in transitioning America to a low carbon economy. This MOU covers, but is not limited to, efforts in the areas of energy efficiency, renewable energy, water efficiency, fossil fuels, alternative fuels, efficient transportation technologies and fueling infrastructure, grid security, smart grid, storage, waste-to-energy, basic science research, mobile/deployable power, small modular reactor nuclear energy, and related areas.

II. Legal Authority

DOE enters into this MOU under the authority of section 646 of the Department of Energy Organization Act (Pub. L. 95-91, as amended; 42 U.S.C. § 7256). DOD enters into this MOU under the authority of DOD Instruction 4000.19 "Inter-Service and Intra-Governmental Support" August 9, 1995.

III. Background

In the 2010 Quadrennial Defense Review, the DOD expressed an intent to partner with other U.S. agencies to research, develop, test, and evaluate new sustainable energy technologies. The DOD aims to speed innovative energy and conservation technologies from laboratories to military end users, and it uses military installations as a test bed to demonstrate and create a market for innovative energy efficiency and renewable energy technologies coming out of DOE laboratories, among other sources. The DOE is currently supporting a range of projects aimed at improving energy efficiency and renewable energy efforts across the military services.

Energy security for the DOD means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational and Installation energy needs. Energy efficiency can serve as a force multiplier, increasing the range and endurance of forces in the field while reducing the number of combat forces diverted to protect energy supply lines, as well as reducing long-term energy costs. DOD is also increasing its use of renewable energy supplies and reducing energy demand to improve energy security and operational effectiveness, reduce greenhouse gas (GHG) emissions in support of U.S. climate change initiatives, and protect the DOD from energy price fluctuations. Solving military challenges through innovation has the potential to yield spin-off technologies that benefit the civilian community as well.

The DOE is the lead Federal agency responsible for the development and deployment of advanced energy technologies, yet DOD will need to invest in many of these same energy technologies as well as other energy technologies which may be unique to DOD's operational requirements. Partnering with DOD provides DOE the opportunity to accelerate the deployment of its technologies and expertise toward the critical economic and energy security needs of the United States and to promote scientific and technological innovation.

The Parties acknowledge the significant positive collaboration that already exists between DOE and DOD and intend through this MOU to strengthen and broaden that cooperation.

IV. Activities

Specific activities covered under this MOU include, but are not limited to:

A. Evaluate energy systems and technology management solutions that meet DOD objectives including developing energy technologies that meet DOD energy requirements. Work collaboratively to identify a strategy for their development and deployment.

B. Maximize DOD access to DOE technical expertise and assistance through cooperation in the deployment and pilot testing of emerging energy technologies. Technology areas may include, but are not limited to, energy efficiency, renewable energy, water efficiency, fossil fuels, alternative fuels, efficient transportation technologies and fueling infrastructure, grid security (e.g., superconductivity, power, electronics, microgrids, cyber, EMP), smart grid, storage, waste-to-energy, basic science research, mobile/deployable power, small modular reactor nuclear energy, and related areas.

C. Expand cooperation related to energy management practices and knowledge exchange, working to ensure that Federal leadership is in compliance with all statutory and Executive Order goals and objectives, particularly in the area of GHG reductions. Encourage the sharing of data, including, but not limited to, data on internal energy management projects and technical assistance projects.

D. Collaborate on science and technology (S&T) projects at research institutions sponsored by either agency. Synchronize research and development (R&D) of new knowledge and technologies to expand complementary efforts.

E. Develop joint initiatives for major energy technology research, development and demonstration programs of mutual interest to DOD and DOE, such as pilot or demonstration facilities which address military needs and also may address national security needs that transcend military requirements. DOD installations may serve as test beds for such technical demonstrations.

F. Develop human capital within DOE and DOD through teaching and education. Work to integrate respective agency energy training and knowledge exchange practices.

G. Encourage professional exchanges and formal liaison relationships between all DOE and DOD components including, but not limited to, laboratory, headquarters, military installations, combatant command headquarters, and forward operating bases.

H. Collaborate on issues regarding nuclear power, except naval nuclear propulsion, including developing a business, licensing and regulatory strategy as appropriate, and evaluating the integration of energy technologies with other industrial applications that support DOD objectives for energy security and GHG reduction. Collaboration will include NRC review and licensing of nuclear power plants that are deployed for DOD purposes, and are located on or adjacent to DOD U.S. installations.

V. Implementation

DOE and DOD intend to develop and conduct cooperative activities relating to identified high priority energy strategic needs, where such cooperation contributes to the efficiency, productivity, and overall success of the activity. The Parties intend for the activities to be executed under the MOU to be established by a joint DOE/DOD senior-level Executive Committee. This Executive Committee will be co-chaired by a designee of the Under Secretary of Defense (Acquisition,

Logistics and Technology) and a designee of the Deputy Secretary from DOE. The Executive Committee will be responsible for the operations and governance of this MOU. Under the direction of the Co-Chairs, the Committee will include representatives from each of the principal DOE offices, specifically, the Office of the Under Secretary for Science, the National Nuclear Security Administration, and the Office of the Under Secretary for Energy. From the Department of Defense representatives will include the Deputy Under Secretary of Defense (Installations and Environment) and the Director of Operational Energy Plans and Programs. Additional members from both Agencies that may be involved in issues or functions of this MOU may be added. Upon agreement of both Departments, the Co-Chairs will appoint a team to develop, within 60 days, a charter and operating structure, membership, products, and decision processes.

The Executive Committee may establish working groups of Federal employees to perform and execute necessary activities contemplated by this MOU at their discretion. The Executive Committee and its working groups may make consensus recommendations based on their collaboration.

The Executive Committee will determine an appropriate regular meeting schedule, not to be less than four times annually. The Co-Chairs will be responsible for the development and distribution of agendas, presentations, and minutes of each meeting. Action items will be clearly identified and tracked in the minutes.

The Co-Chairs will be responsible for any reporting to the appropriate Departmental Secretarial Officers and will outline accomplishments, issues, redirections, and change assessments. The reporting will be coordinated by the Co-Chairs as appropriate.

The Co-Chairs will be responsible for any reports or presentations that are requested by other organizations, subject to the necessary review of each Party.

VI. Funding

Each party intends to coordinate their individual funding and resource decisions in order to maximize the benefits of cooperation under this MOU. Any transfer of funds or sharing of resources between the parties will be pursuant to a separate or pre-existing agreement.

VII. General

Work under this MOU will be jointly planned and monitored by the DOD and DOE.

In the event any activity undertaken by the agencies to implement the purposes of this MOU involves access to and sharing or transfer of technology subject to patents or other intellectual property rights, such access and sharing or transfer will be provided on terms which recognize and are consistent with the adequate and effective protection of intellectual property rights.

This MOU is strictly for internal management purposes for each of the Parties. It is not legally enforceable and shall not be construed to create any legal obligation on the part of either Party. This MOU shall not be construed to provide a private right or cause of action for or by any person or entity.

This MOU in no way restricts either of the Parties from participating in any activity with other public or private agencies, organizations, or individuals.

This MOU is intended to complement, and not to duplicate, cooperation by the Parties under the Memorandum of Understanding between the Department of Energy (National Nuclear Security Administration)/(Office of Science)/(Office of the Under Secretary) and the Department of Defense (Acquisition, Technology and Logistics) concerning Cooperation in a Strategic Partnership to Enhance National Security of January 26, 2009.

All agreements herein are subject to, and will be carried out in compliance with, all Federal applicable laws, regulations and other legal requirements.

This MOU is neither a fiscal nor a funds obligation document. Nothing in this MOU authorizes or is intended to obligate the Parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value.

VIII. Contacts/Designated Representatives

Under Secretary for Science
U.S. Department of Energy
Washington, DC 20585

Under Secretary for Energy
U.S. Department of Energy
Washington, DC 20585

Under Secretary for Nuclear Security
U.S. Department of Energy
Washington, DC 20585

Deputy Under Secretary of Defense
Installations and Environment
U.S. Department of Defense
Washington, DC 20301

Director of Operational Energy Plans and Programs
U.S. Department of Defense
Washington, DC 20301

Deputy Assistant to the Secretary of Defense for Nuclear Matters
U.S. Department of Defense
Washington, D.C. 20301-3050

IX. Duration of Agreement

This MOU is effective on the date of the final signature and will remain in effect until it is terminated by mutual agreement of the Parties or by either Party providing ninety days written notice to the other. This MOU may be modified at any time by written agreement of the Parties. Nothing in this MOU shall be interpreted to limit or otherwise affect any authorities, powers, rights, or privileges accorded to DOD or DOE or any of the officers, employees, or organizational units under any statute, rule, regulation, contract, or agreement.

Daniel B. Poneman
Deputy Secretary of Energy

JUL 22 2010
Date

William J. Lynn III
Deputy Secretary of Defense

JUL 22 2010
Date

APPENDIX B
DA/DOE AVPTA CHARTER

The Deputy Secretary of Energy

and

The Under Secretary of the Army

CHARTER

Advanced Vehicle Power Technology Alliance

I. DESIGNATION

By authority of this charter and effective this date, the Advanced Vehicle Power Technology Alliance (AVPTA) is established. AVPTA shall be active until the charter is rescinded, repealed, terminated or suspended.

II. MISSION

The AVPTA will be a partnership between the Department of the Army (DA) and the Department of Energy (DOE) in accordance with Section IV. E of the Department of Defense (DoD) and DOE Memorandum Of Understanding Concerning Cooperating in a Strategic Partnership to Enhance Energy Security, for the establishment of a joint technology research initiative in the area of ground vehicle power technology research, development and transition. The six focus areas of science and technology are: (1) advanced combustion engines and transmissions; (2) lightweight structures and materials; (3) energy recovery and thermal management; (4) alternative fuels and lubricants; (5) hybrid propulsions systems (including batteries); and (6) analytical tools. Where requirements are common, the two Departments will leverage resources to improve transition of technologies into both the commercial and military marketplace. The Alliance will also leverage industrial research and development (IRAD) involving commercial automotive and defense ground vehicle manufacturers to transition technologies and increase precompetitive research and development.

III. RESPONSIBILITY

The AVPTA is designated as the Department of the Army's and Department of Energy's primary point of contact for automotive power technology in the six areas above. Consistent with applicable law, regulation and policy, the AVPTA may conduct its activities in accordance with such agreements as are deemed necessary for its efficient operation.

APPENDIX B (Cont.)
DA/DOE AVPTA CHARTER

IV. AUTHORITY

The AVPTA is jointly led by the Director, U.S. Army Tank Automotive Research, Development and Engineering Center (hereinafter "Director"), and the Department of Energy Program Manager for Vehicle Technologies (hereinafter "Program Manager"). Both the Director and Program Manager maintain authorities over their respective budgets. The AVPTA conducts activities in accordance with the DOD-DOE Energy Security Memorandum of Understanding. DOE enters into this MOU under the authority of section 646 of the Department of Energy Organization Act (Pub. L. 95-91, as amended; 42 U.S.C. § The Army enters into this MOU under the authority of DOD Instruction 4000.19 "Inter-Service and Intra-Governmental Support" August 9, 1995. The Director and Program Manager are the principle and primary points of contact for the prioritization of automotive/ground vehicle power and energy technologies in the six areas above.

V. COORDINATION

The AVPTA shall, as appropriate, coordinate activities and actions with associated government agencies, industries and academia with a focus on efficient vehicle power systems. The DOE and DA leads will meet on a regular basis to coordinate science and technology (S&T) activities, and will align S&T projects and products where requirements are similar. A yearly meeting will be conducted to assess results, update requirements and determine new joint efforts. Results will be reported back to the Under Secretary of the Army and the Deputy Secretary of Energy.

VI. ADVISORY BOARD

The Director and Program Manager may establish a Senior Advisory Board with other government agencies to review strategic planning and make recommendations on future activities. All activities associated with the Senior Advisory Board will comply with the Federal Advisory Committee Act, 5 U.S.C. App. 2 (FACA) and implementing regulation and policy, as applicable. As authorized by law, regulation and policy, the Senior Advisory Board may seek the individual advice of non-Government employees (*e.g.,* individual members of industry or academia) to secure facts and other information to assist the Senior Advisory Board's review.

VII. LEGAL AUTHORITY

The Director and Program Manager will ensure that the activities of the AVPTA are conducted in a manner consistent with all applicable laws, regulations and policies. In particular, all interactions with industry, academia, or other non-governmental entities will be reviewed in advance by appropriate agency counsel to confirm that any necessary enabling

APPENDIX B (Cont.)
DA/DOE AVPTA CHARTER

authorities exist and to ensure compliance with the FACA and implementing regulations and policies.

VIII. TERMINATION AND REVIEW

This charter shall terminate automatically on the five-year anniversary date unless expressly approved for renewal by the undersigned. This charter will be reviewed by the Director and the Program Manager biannually on its anniversary date to ensure currency, completeness and adequacy. Changes to mission and/or responsibilities will require the review by and approval of the Secretary of the Army and the Secretary of Energy.

Daniel B. Poneman
Deputy Secretary of Energy

Joseph W. Westphal
Under Secretary of the Army

Dated: July 18, 2011

APPENDIX C

BREAKOUT SESSION SUBJECT MATTER EXPERTS

Work Group 1 – Advanced Combustion Engines & Transmissions

Mr. Gary Rogers, FEV, Inc. (Moderator)

Dr. Peter Schihl, Tank Automotive Research, Development and Engineering Center

Mr. John Hubble, Tank Automotive Research, Development and Engineering Center

Dr. Gurpreet Singh, Department of Energy, Vehicle Technologies Programs Office

Dr. Robert Wagner, Oak Ridge National Lab

Dr. Dennis Siebers, Sandia National Lab

Dr. Steve Ciatti, Argonne National Lab

Dr. Walt Bryzik, Wayne State University

Mr. Kevin Sisken, Detroit Diesel

Mr. Michael Claus, Tank Automotive Research, Development and Engineering Center (Recorder)

Work Group 2 – Lightweight Structures & Materials

Dr. Richard Gerth, Tank Automotive Research, Development and Engineering Center (Moderator)

Dr. Doug Templeton, Tank Automotive Research, Development and Engineering Center

Dr. Carol Schutte, Department of Energy, Vehicle Technologies Programs Office

Mr. Dean Paxton, Pacific Northwest National Lab

Dr. David Warren, Oak Ridge National Lab

Dr. Eric Winter, Alcoa, Inc.

Dr. Nicholas Gianaris, Michigan State University

Mr. David Matlock, Colorado School of Mines

Dr. Ray Boeman, Oak Ridge National Lab

Dr. Chris Norfolk, ATI Advanced Materials Division

APPENDIX C (Cont.)

BREAKOUT SESSION SUBJECT MATTER EXPERTS

Work Group 2 – Lightweight Structures & Materials (Cont.)

Ms. Lynne Krogsrud, Tank Automotive Research, Development and Engineering Center (Recorder)

Work Group 3 – Energy Recovery & Thermal Management

Mr. Steve Boyd, Department of Energy, Vehicle Technologies (Moderator)

Mr. Chris Spangler, Tank Automotive Research, Development and Engineering Center

Mr. Rob Smith, Tank Automotive Research, Development and Engineering Center

Mr. Charles Raffa, TPS

Mr. Nick Jankowski, Army Research Laboratory

Mr. Bruce Geil, Army Research Laboratory

Captain Brent Odom, Army Research Laboratory

Mr. John Rugh, National Renewable Energy Lab

Mr. Terry Hendricks, Pacific Northwest National Lab

Dr. Sanjiv Sinha, University of Illinois

Dr. Allen Haynes, Oak Ridge National Lab

Mr. Roland Kibler, NextEnergy

Ms. Alice Gerhardt, Tank Automotive Research, Development and Engineering Center (Recorder)

Work Group 4 – Alternative Fuels & Lubricants

Ms. Pat Muzzell, Tank Automotive Research, Development and Engineering Center (Moderator)

Mr. Kevin Stork, Department of Energy, Vehicle Technologies

Dr. Ivan Lee, Army Research Laboratory

Mr. Allen Comfort, Tank Automotive Research, Development and Engineering Center

Dr. James Edwards, Air Force Research Lab

Dr. George Fenske, Argonne National Lab

APPENDIX C (Cont.)
BREAKOUT SESSION SUBJECT MATTER EXPERTS

Work Group 4 – Alternative Fuels & Lubricants (Cont.)

Dr. Robert McCormick, National Renewable Energy Lab

Mr. Brian West, Oak Ridge National Lab

Dr. Arup Gangopadhyay, Ford Motor Company

Dr. Robert Freerks, Rentech, Inc.

Mr. Ed Frame, Southwest Research Institute

Mr. Paul Michael, Milwaukee School of Engineering

Mr. Nicholas Johnson, Tank Automotive Research, Development and Engineering Center (Recorder)

Work Groups 5a & 5b – Hybrid Propulsion Systems & Batteries/Energy Storage

Dr. Mitch Olszewski, Oak Ridge National Lab (Moderator – Hybrid Propulsion Systems)

Ms. Sonya Zanardelli, Tank Automotive Research, Development and Engineering Center (Moderator – Batteries/Energy Storage)

Dr. Zoran Filipi, University of Michigan

Mr. Todd Fansler, General Motors

Mr. Gus Khalil, Tank Automotive Research, Development and Engineering Center

Dr. Richard Jow, Army Research Laboratory

Mr. Bruce Geil, Army Research Laboratory

Mr. Edwin Owens, Department of Energy, Vehicle Technologies Programs Office

Dr. James Miller, Argonne National Lab

Mr. Mark Mehall, Ford Motor Company

Mr. Justin Holmes, General Dynamics Land Systems

Mr. Nader Nasr, Oshkosh

Dr. Giorgio Rizzoni, Ohio State University

Mr. Ken Winters, DRS

Mr. Porfirio Nogueiro, BAE Systems

APPENDIX C (Cont.)

BREAKOUT SESSION SUBJECT MATTER EXPERTS

Work Groups 5a & 5b – Hybrid Propulsion Systems & Batteries/Energy Storage (Cont.)

Mr. Jim Barnes, U.S. Navy

Mr. Peter Devlin, Department of Energy

Ms. Jay Iyengar, Chrysler

Mr. Paul Savage, Nextek Power Systems

Mr. Gary Gauthier, NextEnergy

Ms. Janie Arafat, Tank Automotive Research, Development and Engineering Center (Recorder – Hybrid Propulsion Systems)

Ms. Shannon Durbin, Tank Automotive Research, Development and Engineering Center (Recorder – Batteries/Energy Storage)

Work Group 6 – Analytical Tools

Mr. Jake Ward, Department of Energy, Vehicle Technologies Programs Office (Moderator)

Dr. Jason Siegel, University of Michigan

Dr. David Lamb, Tank Automotive Research, Development and Engineering Center

Dr. Matt Castanier, Tank Automotive Research, Development and Engineering Center

Mr. Bill Fisher, Army Materiel Systems Analysis Activity

Mr. Aymeric Rousseau, Argonne National Lab

Mr. Aaron Brooker, National Renewable Energy Lab

Mr. Mark Rupersburg, General Dynamics Land Systems

Mr. Paul Weal, LMS International

Dr. Mike Mazzola, Mississippi State University

Mr. Louis Infante, Ricardo

Mr. William Siddall, NextEnergy

Mr. Stephen Nettnin, Tank Automotive Research, Development and Engineering Center (Recorder)

APPENDIX D
WORKSHOP AGENDA

Monday, 18 July 2011

TIME	ACTIVITY	SPEAKER
0730-0755	Registration and Continental Breakfast	
0755-0800	Welcome and Introductions	Mr. Ron Gardhouse President and CEO NextEnergy
0800-0810	Opening Remarks	Dr. Grace M. Bochenek Director, TARDEC
		Mr. Patrick Davis Program Manager Vehicle Technologies DOE-EERE
0810-0820	Opening Remarks	HON Carl Levin U.S. Senator (D-MI)
0820-0835	U.S. Department of Energy Perspective	HON Steven Chu Secretary of Energy
0835-0850	U.S. Department of the Army Perspective	HON Joseph Westphal Under Secretary of the Army
0850-0900	Operational Energy Needs	HON Sharon E. Burke Assistant Secretary of Defense for Operational Energy Plans and Programs
0900-0910	Role of Army Energy	HON Katherine Hammack Assistant Secretary of the Army (Installations Energy and Environment)
0910-0930	Break - Media Q&A	
0930-0945	Automotive Industry Perspective	Dr. Alan Taub VP Global R&D General Motors

APPENDIX D (Cont.)
WORKSHOP AGENDA

Monday, 18 July 2011 (Cont.)

TIME	ACTIVITY	SPEAKER
0945-1000	Warfighter Needs and Imperatives	MG James Hodge Commanding General Combined Arms Support Command (CASCOM)
1000-1015	Breakout Session Instructions	Dr. David Gorsich Chief Scientist, TARDEC
1015-1025	Break	
1025-1130	Begin Breakout Sessions	Work Group Leaders
1130-1700	Working Lunch - Breakout Sessions	

Tuesday, 19 July 2011

TIME	ACTIVITY	SPEAKER
0730-0800	Continental Breakfast	
0800-1200	Continuation of Breakout Sessions (breaks as needed)	Work Group Leaders
1200-1300	Lunch	
1300-1430	Breakout Session Summary Report Briefings	Work Group Leaders
1430-1500	Closing Remarks	Dr. Bochenek Mr. Davis

APPENDIX E
WORKSHOP OUTPUT

Table E-1
DOD & DOE Strategic Drivers

Department of Defense Operational Energy Strategy	Department of Energy Vehicle Technology Program

Vehicle Technologies:
- Increase:
  • Range
  • Endurance
  • Reliability
	Vehicle Technologies:
	- Reduce Weight
	- Increase Powertrain Efficiency
	- Accelerate:
	  • Electrification
	  • Advanced Technology Integration

Fuels: - Reduced Fossil Fuel Reliance	Fuels: - Increase Alternative Fuel Usage
National Goals: - Reduce Green House Gas (GHG) Emissions[2] - Stimulate Civilian Sector Innovation	National Goals: - Reduce dependence on foreign oil by one-third in the next decade - Cut carbon-dioxide emissions by 80% by 2050 - 1 million plug-in hybrid vehicles on the road by 2015

Military Operations:
- Save Lives
- Lighten Logistics Load
- Reduce Supply Vulnerability
- Refocus Combat Resources
- Strengthen:
  • Fuel Price Resiliency
  • Supply Disruption Resistance
- Build Partner Nation Capability & Stability	

[2] Corresponds to DOE Strategic Goal	

APPENDIX E (Cont.)
Table E-2
Research & Development (R&D) Topics

Army Specific	General
Fuels: - JP8 Variability - Heavy	Fuels: - Alternative
Power: - Density	Power: - Generation - Electronics
Engines: - Small Displacement Auxiliary Power Units (APUs)	Engines: - Oil
	Thermal Management Combustion Control Sensors Systems - Climate Control - Fuel Injection - Intake Boost - Safety
	Design: - Holistic - Integration & Packaging Materials - Joining - Characteristics & Properties Manufacturing Processes Thermoelectrics Lubricants Hydraulic Fluids Electro-magnetic Emissions Electric Machines Energy Storage Devices

APPENDIX E (Cont.)
Table E-2 (Cont.)
R&D Topics

Army Specific	General
	Modeling & Simulation (M&S): – Process Efficiency – Multi-dimensional/scaling – Interoperability & Sharing Framework – Analyses: • Cost • Gap – Standards – Predictive Tools – Cross-functional Application Programs

Table E-3
Key Technology Subsets of R&D Topics

R & D Topics	Key Technology(s)
Fuels: – Alternative	Unconventional Fuel Data Test Method Development 'Fit-for-Purpose' Criteria
Power: – Generation	Advanced Materials Modules & Devices Heat Exchangers Validation Data
Power: – Electronics	Liquid Cooling Packaging Inverters DC/DC Converters (DC: Direct Current) Inductors Modeling & Simulation

APPENDIX E (Cont.)
Table E-3 (Cont.)

Key Technology Subsets of R&D Topics

R & D Topics	Key Technology(s)
Engines: - Oil	Test Method Development Advanced Base Fluids Advanced Additives Predictive Modeling & Simulation
Thermal Management	Accessory Drive Fan Control Low Heat Rejection Components & Design High Temperature Materials Load Reduction Advanced Heat Exchangers Coatings Air Cooling
Combustion Control: - Sensors	In-cylinder Pressure Monitoring Low Cost Durability
Systems: - Climate Control	Micro-climates Human Factors Modeling & Simulation
Systems: - Fuel Injection	High Pressure Injection Multi-pulse Injection Micro Injectors Spray Mixture Modeling & Simulation Advanced Materials Injector Nozzle Design
Systems: - Intake Boosting	Novel Designs Advanced Materials
Systems: - Safety	Maintenance Emergency Situations Personnel Education
Design: - Holistic	Light-weighting

APPENDIX E (Cont.)
Table E-3 (Cont.)
Key Technology Subsets of R&D Topics

R & D Topics	Key Technology(s)
Design: - Integration & Packaging	Integrated Cooling Solutions High Ambient Temperature Operating Conditions
Materials: - Joining	Dissimilar Material Joining Modeling & Simulation
Materials: - Characterization, Performance & Properties	Carbon Fiber Composites Aluminum Advanced High Strength Steels
Manufacturing Processes	Modeling & Simulation Carbon Fiber Composites Aluminum Advanced High Strength Steels
Thermoelectric	Advanced Materials Modules & Devices Systems Heat Exchangers
Lubricants	Test Method Development Advanced Base Fluids Advanced Additives Predictive Modeling & Simulation
Hydraulic Fluids	Test Method Development Hydraulic Hybrid Applicable
Electro-magnetic Emissions	Modeling & Simulation
Electric Machines (Motors & Generators)	Permanent Magnet Replacement

APPENDIX E (Cont.)
Table E-3 (Cont.)

Key Technology Subsets of R&D Topics

R & D Topics	Key Technology(s)
Energy Storage Devices	Key Component Development: – Anodes – Cathodes – Electrodes Packaging Manufacturing Battery (Charge/Discharge) Management System Device Modeling & Simulation Testing Abuse Response (Mitigation) Batteries – High Power Li-Ion – High Energy Li-Ion – Li-Air – Lead-Acid Capacitors (Super & Ultra)
Modeling & Simulation: – Process Efficiency – Multi-dimensional/scaling – Interoperability & Sharing Framework – Analyses: • Cost • Gap – Standards – Predictive Tools – Cross-functional Application Programs	As cross-referenced above.

APPENDIX E (Cont.)
Table E-4

Current & Objective Metrics

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology/Metrics	Current	Objective	Current	Objective
Accessory Fan Drive Control: – Commercial – Combat – Tactical	 — 0.6[a] 0.75[a]	 — 0.4[a] 0.6[a]	 1.0[a] — —	 0.75[a] — —
Advanced Materials: – Power Generation – Fuel Injection – Exhaust Temp – Thermoelectric	 150°C 1,500 bar 700°C 5 W/kg	 200°C 2,500 - 3,000 bar 800+°C 8.8 W/kg	 150°C 2,000 bar 700°C —	 200°C 2,500 - 3,000 bar 800+°C 10% FE[b] Improvement
Advanced High Strength Steels	—	2X Ductility Increase at a Given Strength	—	2X Ductility Increase at a Given Strength
Aluminum	—	15% → 20% Increase in Strength/Weight Ratio	—	15% → 20% Increase in Strength/Weight Ratio

[a] Total Heat Rejection/Crankshaft Power
[b] FE: Fuel Economy

APPENDIX E (Cont.)
Table E-4 (Cont.)

Current & Objective Metrics

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology/Metrics	Current	Objective	Current	Objective
Batteries: - Cell Level: • High Energy Li-Ion • High Power Li-Ion[c] • Li-Air - Pack Level: • High Energy Li-Ion • High Power Li-Ion[c] • Lead-Acid[d] • Li-Air	 200 Whr/kg — — 60 Whr/kg (6T) 1 kW/kg 32 Whr/kg —	 400 Whr/kg — 400 - 800 Whr/kg 110 Whr/kg 2 kW/kg @ 40 Whr/kg Current +10% 300 - 400 Whr/kg	 200 Whr/kg 2 kW/kg — 100 Whr/kg 1 kW/kg — —	 400 Whr/kg 2 kW/kg 400 - 800 Whr/kg 150 - 200 Whr/kg 4 kW/kg @ 60 Whr/kg — 300 - 400 Whr/kg
Capacitors (Ultra-): – Cell Level – Pack Level	 — —	 15 Whr/kg 9 Whr/kg	 3 - 5 Whr/kg 2 - 3 Whr/kg	 15 Whr/kg 9 Whr/kg
Carbon Fiber Composites	—	$5/lb	—	$5/lb
DC/DC Converters: – DOD (30kW) – DOE (6 kW)	 — 1.2 kW/l	 — 3 kW/l	 4 - 6 kW/l —	 8 kW/l —
Electric Machines: – Cost – Power Density – Specific Power	 $15 - $20/kW 3 kW/l —	 $10/kW 10 kW/l —	 $11/kW 6.6 kW/l 2.5 kW/kg	 $4.7/kW 5.7 kW/l 1.6 kW/kg

[c] 10 Second Duration
[d] Deep Discharge

APPENDIX E (Cont.)
Table E-4 (Cont.)
Current & Objective Metrics

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology/Metrics	Current	Objective	Current	Objective
Engine Oil: - Increase FE[b] - Reduce: • Boundary Friction • Viscosity	— — 15W40 (15.5 cSt @100°C)	1 – 3% 30 – 90% 0W20 (8 – 9 cSt @ 100°C)	— — —	— — —
Heat Exchanger: - Thermoelectric	5 W/kg	8.8 W/kg	—	10% FE[b] Improvement
High Pressure Fuel Injection Systems	1,500 bar	2,500 – 3,000 bar	2,000 bar	2,500 – 3,000 bar
Inverters: – Cost – Power Density – Specific Power	$150/kW 30 kW/l 20 kW/kg	$50/kW 40 kW/l 30 kW/kg	$23/kW 3.6 kW/l 3.7 kW/kg	$3.3/kW 13.4 kW/l 14.1 kW/kg
Light-weighting: – Holistic Design	—	5% Reduction of Legacy Vehicles	—	—
Liquid Cooling	150 W/cm^2	> 150 W/cm^2	150 W/cm^2	> 150 W/cm^2
Load Reduction (Thermal)	Maintain 85°F Cabin Temp for 8 hrs	—	Attain 81°F Cabin Temp in 15 Minutes	—
[b] FE: Fuel Economy				

APPENDIX E (Cont.)
Table E-4 (Cont.)

Current & Objective Metrics

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology/Metrics	Current	Objective	Current	Objective
Low Heat Rejection Designs:				
– Commercial	—	—	1.0[a]	0.75[a]
– Combat	0.6 – 0.75[a]	0.4[a]	—	—
– Tactical	0.75 – 1.0[a]	0.6[a]	—	—
Gear Lubricants:				
– Increase FE[b]	—	2%	—	—
– Reduce:				
• Boundary Friction	—	30% - 90%	—	—
• Viscosity	80W-90	75W-85	80W-90	75W-85
Modeling & Simulation:				
– Dissimilar Metals Joining	—	100% of Weaker Material[e]	—	100% of Weaker Material[e]
– Human Factors	Maintain 85°F Cabin Temp for 8 hrs	—	Attain 81°F Cabin Temp in 15 min	—
– Spray Mixtures (Fuel Injection)				
Micro-climates (Thermal Management)	Maintain 85°F Cabin Temp for 8 hrs	—	Attain 81°F Cabin Temp in 15 min	—

[a] Total Heat Rejection/Crankshaft Power
[b] FE: Fuel Economy
[e] in Tension and Shear

APPENDIX E (Cont.)
Table E-4 (Cont.)
Current & Objective Metrics

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology/Metrics	Current	Objective	Current	Objective
Multi-pulse Fuel Injection	2,000 bar	2,500 - 3,000 bar	2,000 bar	2,500 - 3,000 bar
Nozzle Design (Fuel Injection)	2,000 bar	2,500 - 3,000 bar	2,000 bar	2,500 - 3,000 bar
Novel Design (Boost System Exhaust Temp)	700°C	800+°C	700°C	800+°C
Packaging (Thermal Management)	150 W/cm^2	> 150 W/cm^2	150 W/cm^2	> 150 W/cm^2
Systems (Thermo-electrics)	5 W/kg	8.8 W/kg	—	10% FE[b] Improvement
Surface Engineering (Low Friction & Lubricant Compatibility): - Improved FE[b]	—	1%	—	1%

[b] FE: Fuel Economy

APPENDIX E (Cont.)
Table E-5

Proposed Prototype Applications & Timeframe

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology	Application	Timeframe (Calendar Year)	Application	Timeframe (Calendar Year)
Advanced Additives: – Engine Oil – Lubricants	Ground Vehicles & Equipment	2016 2016	Ground Vehicles & Equipment	2016 2016
Advanced Base Fluids: – Engine Oil – Lubricants	Ground Vehicles & Equipment	2013 - 2016 2016	Ground Vehicles & Equipment	2013 - 2016 2016
Advanced Materials: – Power Generation – Thermoelectric	— Bradley Exhaust TEG[1]	2020 2015	— Light Duty Vehicle Exhaust TEG	— 2016
Air Cooling Thermal Management	Main Radiator	2017	Inverter Demo	2014
Batteries: – High Energy Li-Ion – High Power Li-Ion – Lead-Acid – Li-Air	Silent Watch SLI[2] & Pulse Power SLI & Silent Watch SLI & Silent Watch	2018 2021 — 2035	EV & PHEV HEV — EV, HEV & PHEV	2018 2021 — 2035
Capacitors	SLI	2016	—	—

[1] TEG: Thermo-Electric Generator
[2] SLI: Starting, Lighting & Ignition

APPENDIX E (Cont.)
Table E-5 (Cont.)

Proposed Prototype Applications & Timeframe

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology	Application	Timeframe (Calendar Year)	Application	Timeframe (Calendar Year)
Coatings	Main Radiator	2017	Inverter Demo	2014
DC/DC Converters	—	2015	—	—
Emergency Situation Safety	—	2020	—	—
'Fit-for-Purpose' Alternate Fuels	Ground Vehicles & Equipment	2013	Ground Vehicles & Equipment	2013
Heat Exchangers: – Power Generation – Thermal Management – Thermoelectric	— Main Radiator Bradley Exhaust TEG[1]	2020 2014 2015	— Inverter Demo Light Duty Vehicle Exhaust TEG	— 2017 2016
High Ambient Temperature Operating Conditions	—	2015	—	—
Hydraulic Hybrid Hydraulic Fluids	Ground Vehicles & Equipment	2014 - 2016	Ground Vehicles & Equipment	2014 - 2016
Inductors	—	2020	—	—

[1] Thermo-Electric Generator

APPENDIX E (Cont.)
Table E-5 (Cont.)
Proposed Prototype Applications & Timeframe

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology	Application	Timeframe (Calendar Year)	Application	Timeframe (Calendar Year)
Integrated Cooling Solutions	—	2015	—	—
Inverters	—	2015	—	—
Light-weighting	Light Armored Vehicle	—	—	—
Liquid Cooled Power Electronics	—	2020	—	—
Load Reduction Thermal Management	Ground Combat Vehicles & Modernizations	2019	EV Demo	2015
Modeling & Simulation:				
– Electromagnetic Emissions	—	2020	—	—
– Engine Oil	Ground Vehicles & Equipment	2016	Ground Vehicles & Equipment	2016
– Human Factors	Ground Combat Vehicles & Modernizations	2019	EV Demo	2015
– Lubricants	Ground Vehicles & Equipment	2016	Ground Vehicles & Equipment	2016
– Power Electronics	—	2020	—	—

APPENDIX E (Cont.)
Table E-5 (Cont.)

Proposed Prototype Applications & Timeframe

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology	Application	Timeframe (Calendar Year)	Application	Timeframe (Calendar Year)
Maintenance Safety	—	2015	—	—
Micro-climates	Ground Combat Vehicles & Modernizations	2019	EV Demo	2015
Modules & Devices – Thermoelectric – Power Generation	Bradley Exhaust TEG[1] —	2015 2020	Light Duty Vehicle Exhaust TEG —	2016 —
Packaging	—	2020	—	—
Permanent Magnet Replacement	—	2020	—	—
Personnel Safety Education	—	2020	—	—
System Thermo-electrics	Bradley Exhaust TEG	2015	Light Duty Vehicle Exhaust TEG	2016

[1] TEG: Thermo-Electric Generator

APPENDIX E (Cont.)
Table E-5 (Cont.)
Proposed Prototype Applications & Timeframe

	Depts. of Army/Defense		Commercial/Dept of Energy	
Key Technology	Application	Timeframe (Calendar Year)	Application	Timeframe (Calendar Year)
Test Methodology Development: - Engine Oil - Alternative Fuels - Hydraulic Fluids - Lubricants	Ground Vehicles & Equipment	2013 - 2016 2013 - 2016 2013 - 2015 2016	Ground Vehicles & Equipment	2013 - 2016 2013 - 2016 2013 - 2015 2016
Unconventional Fuels Data	Ground Vehicles & Equipment	2016	Ground Vehicles & Equipment	2016
Validation Data: - Power Electronics	—	2020	—	—

APPENDIX F

POST WORKSHOP ANALYSIS

Table F-1

Work Group Technology Cross-cut Assessment

Work Group	1	2	3	4	5a	5b	6
1	X	YES	YES	YES	NO	NO	YES
2	YES	X	YES	YES	YES	YES	YES
3	YES	YES	X	YES	YES	YES	YES
4	YES	YES	YES	X	NO	NO	YES
5a	NO	YES	YES	NO	X	YES	YES
5b	NO	YES	YES	NO	YES	X	YES
6	YES	YES	YES	YES	YES	YES	X

Work Group	Technical Focus Area
1	Advanced Combustion Engines & Transmissions
2	Lightweight Structures & Materials
3	Energy Recovery & Thermal Management
4	Alternative Fuels & Lubricants
5a	Hybrid Propulsion Systems
5b	Batteries/Energy Storage
6	Analytical Tools (Modeling & Simulation)

YES - Work Group Technology Focus Areas Cross-cut (81%)

NO - Work Group Technology Focus Areas Do NOT Cross-cut

X – Work Group's Intersection with Itself

Materials, Thermal Management and Analytical Tools (Modeling & Simulation): Work Groups 2, 3 and 6, respectively; cross-cut <u>all seven</u> technology focus areas.

APPENDIX F

Table F-2
R&D TOPICS CROSS-REFERENCED BY KEY TECHNOLOGY

Key Technology	R & D Topics
Advanced Additives	Engine Oils Lubricants
Advanced Base Fluids	Engine oils Lubricants
Advanced High Strength Steel	Manufacturing Processes Material Characterization, Performance & Properties
Advanced Materials	Electric Machines (Motors & Generators) Fuel injection Systems Intake Boost Systems Power Generation Thermal Management Thermo-electrics
Aluminum	Manufacturing Processes Material Characterization, Performance & Properties
Carbon Fiber Composites	Manufacturing Processes Material Characterization, Performance & Properties
Cooling	Integration & Packaging Design Power Electronics Thermal Management
Heat Exchangers	Power Generation Thermal Management Thermo-electrics

APPENDIX F (Cont.)
Table F-2 (Cont.)
R&D TOPICS CROSS-REFERENCED BY KEY TECHNOLOGY

Key Technology	R & D Topics
Modeling & Simulation	Climate Control Systems Electro-magnetic Emissions Energy Storage Devices Engine Oils Fuel Injection Systems Lubricants Manufacturing Processes Dissimilar Materials Joining Power Electronics
Modules & Devices	Power Generation Thermo-electrics
Packaging & Configuration	Energy Storage Power Electronics Power Generation Thermo-electrics
Test Method Development	Alternative Fuels Energy Storage Engine Oils Hydraulic Fluids Lubricants

APPENDIX F

Table F-3

WORK GROUP DEFINED TECHNICAL STRATEGIC DRIVERS

Cited by Work Group(s)*	Depts. of Army/Defense	Commercial/Dept of Energy
	Cross-cuts Commercial and Depts. of Army, Defense & Energy	
5b	Competitive Domestic Policies	
6	Design, Integration, & Fielding of Energy Efficient Vehicles	
	Develop:	
6	- Trusted Models	
5b	- U.S. Industrial Base	
6	Enable Cost-effective Technology Insertion	
6	Evaluate Efficiency & Performance of Vehicle Sub-systems	
6	Improve Modeling & Simulation Process Efficiency	
	Increase:	
3 & 5b	- Overall System/Vehicle Performance	
1 & 4	- Alternative/Renewable Fuel Usage	
6	Next Generation of Modeling & Simulation Engineers	
2	No Response Submitted	
5a & 5b	On-Board Vehicle Power (OBVP)	
	Reduce:	
4 & 6	- Fuel Consumption	
5a	- Weight & Volume	
1, 5a & 5b	- Greenhouse Gas & Particulate Emissions	
5b	Safety	
	Silent:	
5b	- Operation/Watch	
5b	- Mobility	
1	JP8 Variability [(A)]	
3	Platform Compatibility (New v. Legacy)	
1	Power Density [(A)]	
3	Reduce Life-Cycle Costs	
1	Small Engines[(A)]	
[(A)] Indicates Army Specifically Identified vs. "Military" or Dept of Defense		

APPENDIX F (Cont.)

Table F-3 (Cont.)

WORK GROUP DEFINED TECHNICAL STRATEGIC DRIVERS

Cited by Work Group(s)*	Depts. of Army/Defense	Commercial/Dept of Energy
5b		Battery Integration into Drive System
1 & 5b		Improve Efficiency
3		Maintain/Increase Life/Reliability
		Reduce:
1, 3 & 5a		- Design/Development Time/Cost
3		- Energy Consumption
5a		- Petroleum Consumption
4		- Petroleum Demand

*Work Group	Technical Focus Area
1	Advanced Combustion Engines & Transmissions
2	Lightweight Structures & Materials
3	Energy Recovery & Thermal Management
4	Alternative Fuels & Lubricants
5a	Hybrid Propulsion Systems
5b	Batteries/Energy Storage
6	Analytical Tools (Modeling & Simulation)

APPENDIX F

Table F-4

WORK GROUP DEFINED POTENTIAL STRATEGIC DRIVERS/ REQUIREMENTS TRADE-OFF OPPORTUNITIES

Cited by Work Group(s)*	Depts. of Army/Defense	Commercial/Dept of Energy	Generic
	Cross-cuts Commercial, Depts. of Army, Defense & Energy, and Generic Parameters		
	Non-Negotiable:		
3	– Specification/Regulatory/Compliance		
3, 4 & 5b	– Safety		
2	No Response Submitted		
5a	No Trade-off Opportunities Exist		
	Cross-cuts Commercial, Depts. of Army, Defense & Energy Parameters		
1,3,4,5b & 6	Costs: - Design/Development - Initial Acquisition - Operations/Life-Cycle		
1	Efficiency		
1	Heat Rejection		
1	Power Density		
6	Survivability		
1 & 3		Durability/Reliability	
1 & 6		Emissions	
4			Fuel Consumption: – Conventional Fuels – Alternative/Renewable
3 & 6			Performance
3			Physical Constraints
4			Volumetric Energy Density

*Work Group	Technical Focus Area
1	Advanced Combustion Engines & Transmissions
2	Lightweight Structures & Materials
3	Energy Recovery & Thermal Management
4	Alternative Fuels & Lubricants
5a	Hybrid Propulsion Systems
5b	Batteries/Energy Storage
6	Analytical Tools (Modeling & Simulation)

APPENDIX G
POST-WORKSHOP WORK GROUP LEADER FEEDBACK

Q1: On what single Key Technology do you perceive has the greatest joint technical value to DOD and DOE to significantly affect energy?

- More fuel efficient engine oils.
- Multi-scale, multi-dimensional models for vehicle systems and controls.
- Holistic design models for lightweight materials.
- Power electronics (inverters and converters) using wide band gap power devices.
- High-energy Li-Ion battery technology suitable for all-electric vehicles and silent watch applications.

Q2: What single Key Technology do you perceive collaborative work can begin within six months?

- Test method development for engine oil efficiency test.
- Power module packaging for high-temperature applications.
- Low-temperature, high-voltage nonflammable electrolytes.

Q3: What was the most important technical topic your group identified?

- The fuel efficiency gains possible through improved formulations of engine oils, gear oils and hydraulic fluids and the needs for standardized test methods that validate these gains for medium/heavy-duty truck applications.
- Multi-scale, multi-dimensional models for vehicle systems and controls.
- Holistic design models for lightweight materials – it's the most complex topic that addresses all aspects of light-weighting, including requirements definition, software tools/models development, and manufacturing (forming and assembly) processes.
- Power electronics, packaging and electric machines that do not use rare earth permanent magnets. The electric machines could be considered the most important because of China's monopoly of rare earth materials.
- Mapping of respective DOD/DOE Li-Ion battery program activities. This topic discussion led to the understanding that DOD interest in Silent Watch applications matched closely to the DOE interest in high-energy batteries for EV applications.

Q4: What was the most important conclusion your group identified?

- More fuel efficient lubricants for medium/heavy-duty trucks are part of the solution to reducing our nation's and military's demand for petroleum.

- Joint review of DOD/DA and DOE Modeling & Simulation programs developing multi-scale, multi-dimensional models for vehicle systems and controls can identify synergies and gaps, but additional evaluation of third-party Model-Based Systems Engineering Tools is likely to require additional funding.
- Significant advances in power density and specific power can be attained via high-temperature power electronics.
- Greater awareness of activities and progress among and between respective Departments would be very beneficial. Invitations to respective annual reviews and meetings of that type would facilitate greater cross-flow of information.
- There are a number of opportunities for better coordination between the respective Departments battery programs, including information sharing from existing projects. The scale-up work getting underway at the Argonne National Lab, where both departments are funding activities, is an excellent example.

Q5: What do you see as being the highest priority next-step recommendation(s) following the Workshop?

- Respective Department management direction including:
  - Detailed overview of the Alliance framework including future events, reporting mechanisms, collaboration tools, etc.
  - Project review and selection process, criteria
  - Project funding process
  - TARDEC personnel assignments, priorities and responsibilities
- Establish formal methods for exchanging technical and contact information between the Departments
- Establish Army-led working groups in lightweight materials
- Integrate defense industry Original Equipment Manufacturers (OEMs) into AVPTA activities
- Develop a mechanism for encouraging and assessing coordination and cooperation between the Departments to help promote and institutionalize technical interaction.

APPENDIX H
LIST OF ACROYNYMS

°C	Degrees Celsius
°F	Degrees Fahrenheit
ACEC	Advanced Combustion & Emissions Control
AESIP	Army Energy Security Implementation Plan
Al	Aluminum
AMC	Army Materiel Command
ANL	Argonne National Laboratory
APU	Auxilary Power Unit
ARC	Automotive Research Center
ARL	Army Research Laboratory
ARPA-E	Advanced Research Projects Agency - Energy
AVPTA	Advanced Vehicle Power Technology Alliance
BAA	Broad Agency Announcement
BEV	Battery Electric Vehicle
CAEBAT	Computer-Aided Engineering for Electric Drive Vehicle Batteries
CAFE	Corporate Average Fuel Economy
CERDEC	Communications-Electronics Research, Development & Engineering Center
CFD	Computational Fluid Dynamics
cm	Centimeter(s)
CRADA	Cooperative Research And Development Agreement
cSt	CentiStoke(s)
CVT	Continuously Variable Transmission
DA	Department of the Army
DC	Direct Current

APPENDIX H (Cont.)
LIST OF ACROYNYMS

DCT	Dual Clutch Transmission
DEER	Directions in Engine-Efficiency & Emissions Research
DF-2	Diesel Fuel (Type 2)
DI	Direct Injection
DOD	Department of Defense
DOE	Department of Energy
DRIVE	Drive-cycle Rapid Investigation, Visualization & Evaluation (tool – National Renewable Energy Laboratory developed software)
EERE	(Office of) Energy Efficiency & Renewable Energy
FCS	Future Combat System
FE	Fuel Economy
FED	Fuel Efficient Demonstrator
FLTT	Fuels and Lubricants Technology Team
FY	Fiscal Year
GaN	Gallium Nitride
GHG	Green House Gases
HCCI	Heterogeneous Charge Compression Ignition
HD	Heavy Duty
HEV	Hybrid Electric Vehicle
IAPG	Inter-Agency Power Group
IPRs	In-Process Reviews
IRAD	Internal Research And Development
JP-8	Jet [Fuel] Propellant - 8
kg	Kilograms

APPENDIX H (Cont.)

LIST OF ACROYNYMS

kW	Kilowatts
l	Liter
Li	Lithium
LSDC	Large Scale Duty Cycle
LTC	Low Temperature Combustion
Mg	Magnesium
MOU	Memorandum Of Understanding
M&S	Modeling & Simulation
NAS	National Academies of Science
NATO	North Atlantic Treaty Organization
NREL	National Renewable Energy Laboratory
OBVP	On-Board Vehicle Power
OEM	Original Equipment Manufacturer(s)
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
PHEV	Plug-in Hybrid Electric Vehicle
PNNL	Pacific Northwest National Laboratory
R&D	Research & Development
RDECOM	Research, Development and Engineering Command
RDT&E	Research, Development, Testing & Engineering
RFP	Request For Proposal
SBIR	Small-Business Innovative Research
SiC	Silicon Carbide
SLI	Starting, Lighting and Igniting/Ignition

APPENDIX H (Cont.)
LIST OF ACROYNYMS

SME	Subject Matter Expert
TARDEC	Tank Automotive Research, Development & Engineering Center
TE	Thermo-Electric
TEG	Thermo-Electric Generator
TM	Thermal Management
USDRIVE	United States Driving Research & Innovation for Vehicle efficiency and Energy sustainability
VTP	(DOE-EERE) Vehicle Technology Programs
W	Watts
WBG	Wide Band Gap
Whr	Watt-hour(s)